# Overview of KLOE results on kaon physics and KLOE–2 perspectives

*Eryk* Czerwiński[1,⋆] on behalf of the KLOE-2 Collaboration

[1] *Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Kraków, Poland*

**Abstract.** Kaon physics program of KLOE is being continued at the upgraded KLOE-2 system, therefore an overview of KLOE results in this field is shortly presented together with prospects for KLOE-2.

## 1 Introduction

The National Laboratory in Frascati (LNF-INFN, Italy) hosts the $e^+e^-$ collider known as $\phi$-factory DA$\Phi$NE [1–3]. The collider was designed to operate at the peak of $\phi$ resonance ($\sqrt{s} = m_\phi \approx 1019\ MeV$) producing $\phi$ mesons almost at rest ($\beta_\phi \approx 0.015$) since electrons and positrons collide with small transverse momenta. A $\phi$ meson decays mostly into kaon pairs (49% into $K^+K^-$ and 34% into $K_SK_L$), which makes a $\phi$-factory the natural place for kaon physics studies. From 2001 to 2006 KLOE has collected 2.5 $\mathrm{fb}^{-1}$ of integrated luminosity [4]. The detector consists of a cylindrical drift chamber [5] and an electromagnetic calorimeter [6] surrounded by a superconducting coil which produces an axial magnetic field parallel to the beam axis.

At KLOE, reconstruction of the $K_S$ decay close to interaction region (clean selection of $K_S \to \pi^+\pi^-$, BR=69%) allows to tag a $K_L$ presence which makes KLOE an excellent place for $K_L$ decay measurements. Additionally a detection of the $K_L$ hit in the calorimeter module tags the presence of the $K_S$, which makes KLOE a unique place to study pure $K_S$ beams e.g. the measurement of $BR(K_S \to \pi^0\pi^0\pi^0)$. A study of both kaons decays in single event is also possible. Since both of them are produced in a pure quantum state ($J^{PC} = 1^{--}$), it is possible to study e.g. quantum interference effects.

At KLOE, the physics program was related to the good accuracy of reconstruction of $K_L$ decays in large fiducial volume, while at KLOE-2 an increased interest will be focused on the physics close to the interaction point as rare $K_S$ decays, $K_S - K_L$ interference, multi-lepton events, as well as $\eta$, $\eta'$ and $K^\pm$ decays. More details about whole KLOE-2 physics program can be found in Ref. [7]. The main modification of KLOE system from the point of view of kaon physics is installation of a light-material Inner Tracker detector based on the Cylindrical GEM technology to improve charged vertex reconstruction and to increase the acceptance for low transverse momentum tracks [8–11].

⋆e-mail: eryk.czerwinski@uj.edu.pl

| Parameter | Measurement | Ref. |
|---|---|---|
| $\mathrm{BR}(K_{e3}) = 0.4008(15)$<br>$\mathrm{BR}(K_{\mu 3}) = 0.2699(14)$ | based on $13 \times 10^6$ $K_L$ decays<br>tagged by $K_S \to \pi^+\pi^-$ | [12] |
| $\tau_L$=50.92(30) ns | fit the time dependence over<br>$0.4\tau_L$ of $8.5 \times 10^6$ $K_L \to 3\pi^0$ decays<br>tagged by $K_S \to \pi^+\pi^-$ | [13] |
| $\lambda'_+ = (25.5 \pm 1.8) \times 10^{-3}$<br>$\lambda''_+ = (1.4 \pm 0.8) \times 10^{-3}$ | based on $2 \times 10^6$ $K_{L,e3}$ decays<br>tagged by $K_S \to \pi^+\pi^-$ | [14] |
| $\mathrm{BR}(K_S \to \pi e \nu) = 7.046(91) \times 10^{-4}$ | from tagged $K_S$ beam<br>$1.2 \times 10^8$ events<br>(20% of full data sample) | [14] |
| $\lambda'_+ = (25.6 \pm 1.5_{stat} \pm 0.9_{syst}) \times 10^{-3}$<br>$\lambda''_+ = (1.5 \pm 0.7_{stat} \pm 0.4_{syst}) \times 10^{-3}$<br>$\lambda_0 = (15.4 \pm 1.8_{stat} \pm 1.3_{syst}) \times 10^{-3}$ | based on $1.8 \times 10^6$ $K_{L,\mu 3}$ decays<br>tagged by $K_S \to \pi^+\pi^-$ and<br>from combined with with $K_{L,e3}$ data | [15] |

**Table 1.** Summary of KLOE results from neutral kaons useful for $V_{\mathrm{us}}$ measurement.

## 2 CKM matrix

The measurement of the CKM mixing matrix element $V_{\mathrm{us}}$ and information about lepton universality is provided at KLOE by precise measurements of semileptonic kaon decay rates. The ratio $\Gamma(K \to \mu\nu)/\Gamma(\pi \to \mu\nu)$ from the leptonic kaon decays is an independent measurement of $|V_{\mathrm{us}}|^2 / |V_{\mathrm{ud}}|^2$, which, together with the result of $|V_{\mathrm{ud}}|$ from the superallowed $0^+ \to 0^+$ nuclear $\beta$ transitions and $V_{\mathrm{ub}}$ from semileptonic $B$ decays provide the most precise test of the CKM matrix unitarity using relation $|V_{\mathrm{ud}}|^2 + |V_{\mathrm{us}}|^2 + |V_{\mathrm{ub}}|^2 = 1$. At the present level of accuracy $|V_{\mathrm{ub}}|^2$ can be neglected. This allows the universality of lepton and quark weak couplings to be tested.

The kaon semileptonic decay rate is given by:

$$\Gamma(K_{l3}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{\mathrm{us}}|^2 |f_+(0)|^2 I_{K,l}(\lambda)(1 + 2\Delta_K^{SU(2)} + 2\Delta_{K,l}^{EM}) \tag{1}$$

where $K = K^0, K^\pm$, $l = e, \mu$ and $C_K$ is the Clebsch-Gordan coefficient, equal to $1/2$ and 1 for $K^\pm$ and $K^0$, respectively. The experimental input is the decay width $\Gamma(K_{l3})$ obtained from the kaon lifetime and the semileptonic BRs, inclusive of radiation, while the theoretical inputs are: the form factor $f_+(0) \equiv f_+^{K^0\pi^-}(0)$ evaluated at zero momentum transfer, the long-distance electromagnetic corrections $\Delta_{K,l}^{EM}$, the universal short-distance electroweak correction $S_{EW} = 1.0232$ and the SU(2)-breaking $\Delta_K^{SU(2)}$. One or more slope parameters $\lambda$, measured from the decay spectra, are used to describe the form factor dependence on the momentum transfer which enters in the phase space integral $I_{K,l}(\lambda)$. KLOE has measured all relevant inputs for charged and neutral kaons: BR's, lifetimes ($K_L$, $K^\pm$), form factors.

The inputs for $|V_{\mathrm{us}}|$ from the neutral kaons measurements at KLOE are gathered in table 1. The world average error on $V_{us} f_+(0)$ value determination is 0.19% [16], while taking into account KLOE results only it is 0.28% [17]. Combining these results together with the 5 fb$^{-1}$ data foreseen at KLOE-2, we can improve the accuracy on the measurement of the $K_L$ lifetime and $K_{Se3}$ branching ratio. Statistical uncertainties on BRs and lifetimes have been obtained scaling present KLOE statistics to 5 fb$^{-1}$ total integrated luminosity, while systematic errors have been estimated conservatively. The expected accuracies are presented in table 2.

| | | World average [16] | | | | | KLOE-2 prospects with 5 fb$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode | $V_{us} f_+(0)$ | % err | BR | $\tau$ | $\Delta$ | $I$ | % err | BR | $\tau$ | $\Delta$ | $I$ |
| $K_{Le3}$ | 0.2163(6) | 0.26 | 0.09 | 0.20 | 0.11 | 0.05 | 0.20 | 0.09 | 0.13 | 0.11 | 0.06 |
| $K_{L\mu3}$ | 0.2166(6) | 0.28 | 0.15 | 0.18 | 0.11 | 0.06 | 0.24 | 0.15 | 0.13 | 0.11 | 0.08 |
| $K_{S\,e3}$ | 0.2155(13) | 0.61 | 0.60 | 0.02 | 0.11 | 0.05 | 0.32 | 0.30 | 0.03 | 0.11 | 0.06 |
| $K^{\pm}_{e3}$ | 0.2172(8) | 0.36 | 0.27 | 0.06 | 0.23 | 0.05 | 0.48 | 0.25 | 0.05 | 0.40 | 0.06 |
| $K^{\pm}_{\mu3}$ | 0.2170(11) | 0.51 | 0.45 | 0.06 | 0.23 | 0.06 | 0.48 | 0.27 | 0.05 | 0.39 | 0.08 |
| Average | 0.2165(4) | 0.19 | | | | | 0.14 | | | | |

**Table 2.** Comparison of world average value of $V_{us} f_+(0)$ [16] with KLOE-2 prospects [7].

The present fractional experimental uncertainty on $V_{\mathrm{us}} f_+(0)$ equal to 0.19% can be reduced to 0.14%, using KLOE and KLOE-2 statistics and combining with world average. This result together with more precise measurements of $f_+(0)$ and $V_{\mathrm{ud}}$ would allow to obtain precision at the level of a $10^{-4}$ in the test on the unitarity relation.

## 3 Charge asymmetry of $K_S$

The charge asymmetry for semileptonic decays of neutral kaons can be defined with $K_S$ and $K_L$ semileptonic decay widths as follows:

$$\begin{aligned} A_{S,L} &= \frac{\Gamma(K_{S,L} \to \pi^- e^+ \nu) - \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})}{\Gamma(K_{S,L} \to \pi^- e^+ \nu) + \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})} \\ &= 2\left[Re\left(\epsilon_{S,L}\right) - Re(y) \pm Re(x_-)\right] \end{aligned} \tag{2}$$

to the first order in parameters $\epsilon_S$, $\epsilon_L$ which can be expressed in terms of the CP and CPT violation parameters $\epsilon_K$ and $\delta_K$:

$$\epsilon_{L/S} = \epsilon_K \mp \delta_K. \tag{3}$$

The semileptonic kaon decays ($K \to \pi e \nu$) can be described with the following decay amplitudes:

$$\begin{aligned} \langle \pi^- e^+ \nu | \, H_{weak} \, | K^0 \rangle &= \mathcal{A}_+, \\ \langle \pi^+ e^- \bar{\nu} | \, H_{weak} \, | \bar{K^0} \rangle &= \bar{\mathcal{A}}_-, \\ \langle \pi^+ e^- \bar{\nu} | \, H_{weak} \, | K^0 \rangle &= \mathcal{A}_-, \\ \langle \pi^- e^+ \nu | \, H_{weak} \, | \bar{K^0} \rangle &= \bar{\mathcal{A}}_+, \end{aligned} \tag{4}$$

where $H_{weak}$ stands for weak Hamiltonian. One introduces the following useful notation:

$$\begin{aligned} x &= \frac{\bar{\mathcal{A}}_+}{\mathcal{A}_+}, \qquad \bar{x} = \left(\frac{\mathcal{A}_-}{\bar{\mathcal{A}}_-}\right)^*, \qquad y = \frac{\bar{\mathcal{A}}^*_- - \mathcal{A}_+}{\bar{\mathcal{A}}^*_- + \mathcal{A}_+}, \\ x_\pm &= \frac{x \pm \bar{x}^*}{2} = \frac{1}{2}\left[\frac{\bar{\mathcal{A}}_+}{\mathcal{A}_+} \pm \left(\frac{\mathcal{A}_-}{\bar{\mathcal{A}}_-}\right)^*\right]. \end{aligned} \tag{5}$$

Sum and difference of the $A_S$ and $A_L$ allow to search for the CPT symmetry violation, either in the decay amplitudes through the parameter $y$ or in the mass matrix through the parameter $\delta_K$:

$$\begin{aligned} A_S + A_L &= 4Re(\epsilon) - 4Re\,(y)\,, \\ A_S - A_L &= 4Re(\delta_K) + 4Re\,(x_-)\,. \end{aligned} \tag{6}$$

The charge asymmetry was measured by the KTeV experiment for long-lived kaon [18] and by the KLOE - for the short-lived one [14]:

$$\begin{aligned} A_L &= (3.322 \pm 0.058_{stat} \pm 0.047_{syst}) \times 10^{-3}, \\ A_S &= (1.5 \pm 9.6_{stat} \pm 2.9_{syst}) \times 10^{-3}. \end{aligned} \tag{7}$$

These results allow for the most precise tests of the CPT symmetry in semileptonic decays of neutral kaons, although the accuracy on $A_L$ is more than two orders of magnitude better then on the $A_S$. Additionally, the total error on $A_S$ is dominated by the available statistics.

Presently the KLOE data set of 1.7 fb$^{-1}$ is being reanalysed aiming at the determination of the semileptonic asymmetry for $K_S$. As the analyzed data sample is 4 times larger, an twofold reduction of the statistical error is expected. Moreover, the KLOE-2 experiment arises prospects of measuring $A_S$ with a statistical uncertainty at the level of $3 \times 10^{-3}$.

## 4 Rare $K_S$ decays

The mechanisms of the CP violation can be investigated by searches of the CP-prohibited rare decays $K_S \to 3\pi^0$. The channel $K_S \to 3\pi^0$ is a pure CP-violating process whereas $K_S \to \pi^+\pi^-\pi^0$ violates CP for I=1 or 3 in the final state. This CP violation is usually expressed in terms of the following amplitude ratios:

$$\begin{aligned} \eta_{+-0} &= \frac{\langle \pi^+\pi^-\pi^0 | H | K_S \rangle}{\langle \pi^+\pi^-\pi^0 | H | K_L \rangle} = \epsilon_K + \epsilon'_{+-0}, \\ \eta_{000} &= \frac{\langle \pi^0\pi^0\pi^0 | H | K_S \rangle}{\langle \pi^0\pi^0\pi^0 | H | K_L \rangle} = \epsilon_K + \epsilon'_{000}, \end{aligned} \tag{8}$$

where $\epsilon'_{+-0}$ and $\epsilon'_{000}$ describe CP violation in decay.

The KLOE experiment set the most precise upper limit on BR($K_S \to 3\pi^0$) using 1.7 fb$^{-1}$ data-set [19]:

$$\mathrm{BR}(K_S \to 3\pi^0) < 2.6 \times 10^{-8}, \tag{9}$$

based on a kinematic fit, testing of signal and background hypotheses and kinematical differences between $K_S \to 2\pi^0$ and $K_S \to 3\pi^0$. This result allows for constraining $|\epsilon'_{000}| \leq 0.0088$ at 90% CL. The sensitivity on BR($K_S \to 3\pi^0$) can be improved to $10^{-8}$ with 5 fb$^{-1}$ data-set to be collected by the KLOE-2 experiment.

Presently, the direct search of $K_S \to \pi^+\pi^-\pi^0$ is being performed on the same KLOE data set. The best value of the branching ratio for this process is an average of three indirect measurements with uncertainty at the level of 30% [20], while the ongoing analysis of KLOE data shows a possibility to obtain the relative uncertainty below 20% in a direct measurement.

## 5 Quantum Mechanics and CPT symmetry tests

Neutral kaons produced from decay of $\phi$ meson are in an entangled states. If both kaons decay into identical final states, e.g. $\pi^+\pi^-$ the decay rate of the system is proportional to:

$$I(\pi^+\pi^-, \pi^+\pi^-, \Delta t) \propto e^{-\Gamma_L \Delta t} + e^{-\Gamma_S \Delta t} - 2e^{-\frac{\Gamma_L + \Gamma_S}{2}\Delta t} cos(\Delta m \Delta t), \tag{10}$$

where $\Delta m$ is the mass difference between $K_L$ and $K_S$, $\Delta t$ is the difference of decay times of two kaons. Presence of the interference term $2e^{-\frac{\Gamma_L + \Gamma_S}{2}\Delta t} cos(\Delta m \Delta t)$ implies that the kaons cannot decay at the same time, and it is an example of correlation of the type pointed out for the first time by Einstein, Podolsky and Rosen [21].

Both, T and CPT symmetry tests at KLOE-2 require identification of $K_S \to \pi\pi$, $K_L \to \pi^{\pm}\ell^{\mp}\nu$ and $K_S \to \pi^{\pm}\ell^{\mp}\nu$, $K_L \to 3\pi^0$ events. Reconstruction of $K_L \to 3\pi^0 \to 6\gamma$ decay has to be performed based on the calorimeter measurement only. The new reconstruction method is similar to Global Positioning System (GPS). For each cluster a sphere centered at its position is created. This sphere with unknown radius represents possible origin points of $\gamma$. The point of $K_L \to 3\pi^0 \to 6\gamma$ is identified as intersection of 6 such spheres (a common origin point of all photons).

### 5.1 Decoherence

It is physically possible that the coherent state of two kaons emerging from the phi decay can factorize and loose coherence [22]. The amount of deviation from prediction of quantum mechanics can be parametrized as the decoherence parameter $\zeta$ suppresing the interference in the following way:

$$I(\pi^+\pi^-, \pi^+\pi^-, \Delta t) \propto e^{-\Gamma_L \Delta t} + e^{-\Gamma_S \Delta t} - 2(1-\zeta_{SL}) e^{-\frac{\Gamma_L + \Gamma_S}{2}\Delta t} cos(\Delta m \Delta t) . \tag{11}$$

The usual quantum mechanics case corresponds to $\zeta = 0$, while $\zeta = 1$ implies the total decoherence. In general $\zeta$ depends on the basis in which the initial state is expressed. KLOE measured the decoherence parameter based on $\approx$1.5 fb$^{-1}$ data sample [23]. The experimental points of signal events $\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ were fitted with Eq. 11 modified with parameters expressing decoherence. The fit was performed taking into account resolution and detection efficiency, the background from coherent and incoherent $K_S$ regeneration on the beam pipe wall, and the small contamination from the non-resonant $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ channel. The obtained results show no deviation from quantum mechanics within the accuracy [23]:

$$\begin{aligned} \zeta_{SL} &= (0.3 \pm 1.8_{stat} \pm 0.6_{syst}) \cdot 10^{-2} , \\ \zeta_{0\bar{0}} &= (1.4 \pm 9.5_{stat} \pm 3.8_{syst}) \cdot 10^{-7} . \end{aligned} \tag{12}$$

Increased statistics at KLOE-2 together with the usage of the inner tracker would allow to reach factor four of improvement in sensitivity.

### 5.2 CPT and Lorentz invariance test

In the framework of the Standard Model Extension (SME) [24–26], the $\delta_K$ parameter depends on the kaon four-momentum in the following way:

$$\delta_K \approx i \sin\phi_{SW} e^{i\phi_{SW}} \gamma_K (\Delta a_0 - \vec{\beta}_K \cdot \Delta\vec{a})/\Delta m, \tag{13}$$

where $\gamma_K$ and $\vec{\beta}_K$ are the boost factor and velocity of the kaon in the observer rest frame, respectively, $\phi_{SW} = \arctan(2\Delta m/\Delta\Gamma)$ is the superweak phase with $\Delta m$ and $\Delta\Gamma$ the differences of mass and width between $K_S$ and $K_L$, respectively, and $\Delta a_\mu$ are four $CPT$ and Lorentz violating coefficients. The experimental observable at fixed time difference $\Delta\tau = \tau_1 - \tau_2$ is therefore the following [22]:

$$I_{f_1 f_2}(\Delta\tau) \propto e^{-\Gamma|\Delta\tau|} \left[ |\eta_1|^2 e^{\frac{1}{2}\Delta\Gamma\Delta\tau} + |\eta_2|^2 e^{\frac{1}{2}\Delta\Gamma\Delta\tau} - 2\mathrm{Re}\left(\eta_1 \eta_2^* e^{-i\Delta m \Delta\tau}\right) \right] \tag{14}$$

where $\eta_j = \left\langle f_j \right| T \left| K_L \right\rangle / \left\langle f_j \right| T \left| K_S \right\rangle \simeq \epsilon_K - \delta_K(\vec{p}_j, t_s)$, $f_1$ and $f_2$ denote kaon final states, $\Gamma = \Gamma_S + \Gamma_L$. In the reported measurement $f_1 = f_2 = \pi^+\pi^-$ and due to the fully destructive quantum interference at $\Delta\tau = 0$ the distribution (14) is sensitive to the $\eta_1/\eta_2$ ratio. This analysis is based on looking for a possible dependence of $I_{f_1 f_2}(\Delta\tau)$ on a sidereal time.

The data sample of 1.7 fb$^{-1}$ total integrated luminosity was analyzed to select $\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ events selected using the invariant mass of pairs of particles, two-body kinematics and missing momentum and energy. The total contamination from background events was established from the Monte Carlo simulation and amounts to 1.5% coming mostly from kaons regenerated without momentum deflection. Selected events were transformed to the sidereal frame and K mesons were labeled accordingly to their momentum direction (forward, backward) with respect to the momentum of the $\phi$ meson. The two data samples are further divided into four 6 h long sidereal time periods, so finally the fit of distribution (14) is performed to eight data subsets. It results with the first measurement of all four parameters in the kaon sector and at present the most precise measurement of these parameters in the quark sector of SME [27]:

$$
\begin{aligned}
\Delta a_0 &= (-6.0 \pm 7.7_{stat} \pm 3.1_{syst}) \times 10^{-18}\ \text{GeV},\\
\Delta a_x &= (\ \ 0.9 \pm 1.5_{stat} \pm 0.6_{syst}) \times 10^{-18}\ \text{GeV},\\
\Delta a_y &= (-2.0 \pm 1.5_{stat} \pm 0.5_{syst}) \times 10^{-18}\ \text{GeV},\\
\Delta a_z &= (\ \ 3.1 \pm 1.7_{stat} \pm 0.5_{syst}) \times 10^{-18}\ \text{GeV}.
\end{aligned}
$$

The ongoing data-taking campaign of KLOE-2 at upgraded DAΦNE collider will improve statistical uncertainties due to higher luminosity of the collider and at the same time systematic uncertainties due to the installation of the Inner Tracker detector [8, 10, 11]. The Inner Tracker will improve resolution on the vertex position and acceptance for tracks with low transverse momentum. Expected accuracies on $\Delta a_0$, $\Delta a_{X,Y}$ and $\Delta a_Z$ are (5.2, 1.3 and 2.2)$\times 10^{-18}$, respectively.

### 5.3 CPT and T symmetry test in transition

A direct test of the T symmetry is possible at the KLOE-2 detector with neutral kaons [28]. These states can be defined as states with definite flavour of CP:

$$
\begin{aligned}
\mathcal{S}\,|\mathrm{K}^0\rangle &= +1\,|\mathrm{K}^0\rangle,\\
\mathcal{S}\,|\bar{\mathrm{K}}^0\rangle &= -1\,|\bar{\mathrm{K}}^0\rangle,
\end{aligned}
\tag{15}
$$

$$
\begin{aligned}
|\mathrm{K}_+\rangle &= \frac{1}{\sqrt{2}}\left[|\mathrm{K}^0\rangle + |\bar{\mathrm{K}}^0\rangle\right] \ \text{withCP} = +1,\\
|\mathrm{K}_-\rangle &= \frac{1}{\sqrt{2}}\left[|\mathrm{K}^0\rangle - |\bar{\mathrm{K}}^0\rangle\right] \ \text{withCP} = -1,
\end{aligned}
\tag{16}
$$

and identified through observation of their decay products. At the moment of decay of the first kaon the state of the second, still-living kaon is immediately known (due to quantum entanglement). Identification of its state at the moment of decay after time $\Delta t$ allows to observe a transition between the strangeness and CP-definite states. For each of the possible transitions a time-dependent ratio of probabilities can be defined as an observable of the T symmetry test. Two of those ratios can be measured at KLOE-2:

$$
R_2(\Delta t) = \frac{P[\mathrm{K}^0(0) \to \mathrm{K}_-(\Delta t)]}{P[\mathrm{K}_-(0) \to \mathrm{K}^0(\Delta t)]} \sim \frac{\mathrm{I}(\ell^-, 3\pi^0; \Delta t)}{\mathrm{I}(\pi\pi, \ell^+; \Delta t)}, \tag{17}
$$

$$
R_4(\Delta t) = \frac{P[\bar{\mathrm{K}}^0(0) \to \mathrm{K}_-(\Delta t)]}{P[\mathrm{K}_-(0) \to \bar{\mathrm{K}}^0(\Delta t)]} \sim \frac{\mathrm{I}(\ell^+, 3\pi^0; \Delta t)}{\mathrm{I}(\pi\pi, \ell^-; \Delta t)}. \tag{18}
$$

with a sensitivity at the level of $10^{-3}$. Asymptotically, their deviation from unity should be proportional to real part of $\delta_K$ which is a T violating parameter of the neutral kaon system [28].

Constructing time-dependent ratios sensitive to CPT violation is also possible [29]:

$$R_{2,CPT}(\Delta t) = \frac{P[\mathrm{K}^0(0) \to \mathrm{K}_-(\Delta t)]}{P[\mathrm{K}_-(0) \to \mathrm{K}^0(\Delta t)]}, \tag{19}$$

$$R_{4,CPT}(\Delta t) = \frac{P[\bar{\mathrm{K}}^0(0) \to \mathrm{K}_-(\Delta t)]}{P[\mathrm{K}_-(0) \to \bar{\mathrm{K}}^0(\Delta t)]}. \tag{20}$$

leading to a double ratio as CPT violation observable in the $\Delta t \gg \tau_S$ limit is equal to $1 - 8\Re\delta_K - 8\Re x_-$. Again, possible deviation from unity would inform about CPT noninvariance [29]. So far, this parameter was not measured, but it is one of the KLOE-2 milestones.

## 6 Summary

In the recent years a long list of physics results from neutral kaon was provided by the KLOE experiment: measurement of $V_{us}$, study of CP and CPT discrete symmetries, search for decoherence of entangled kaons. Presently the KLOE-2 detector is collecting new data sample for broader and more precise results.

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